NuFact 2022
Salt Lake City, Utah, United States
July 31st - Aug. 6th, 2022
The 23rd International Workshop on Neutrinos from Accelerators

KEK 加速器だから見える世界。 Insight through Accelerators.
素粒子原子核研究所 Institute of Particle and Nuclear Studies
大強度陽子加速器施設 J-PARC Japan Proton Accelerator Research Complex

WG3 summary

(Accelerator physics working group)

Natalia Milas (ESS)
Katsuya Yonehara (Fermilab)
Tsunayuki Matsubara (KEK/J-PARC)

WG3 talks

Total 23 talks

- Plenary session (3 talks)
- 6 parallel sessions (18 talks)
- 1 joint session with WG4 (2 talks from WG3)

Rough grouping from my perspective

- Super beams : NuMI/LBNF, J-PARC, ESS/ESSnuSB (7 talks)
- Material studies & beam diagnosis for high power beam (5 talks)
- Muon collider/Future neutrino facilities (7 talks)
- Other unique beam facilities (4 talks)

Speakers will
be shown here
in the slides

Super beams :
NuMI/LBNF, J-PARC, ESS/ESSnuSB

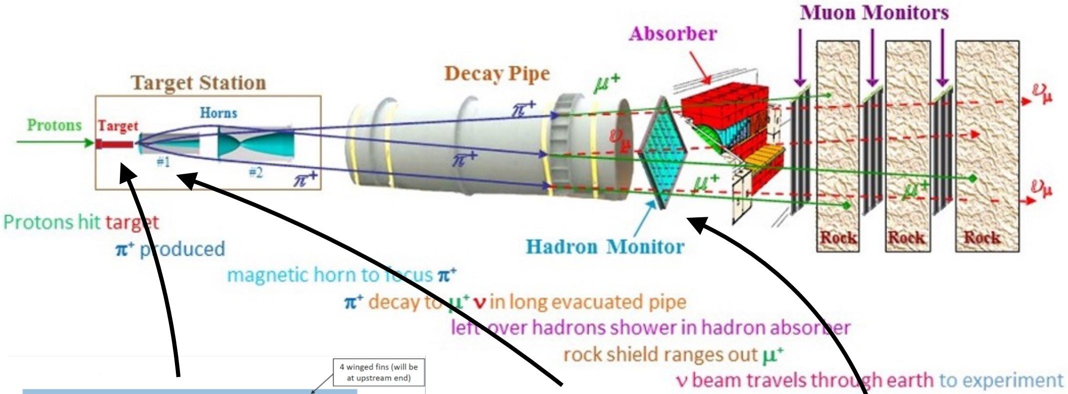
Fermilab

大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex

EUROPEAN
SPALLATION
SOURCE

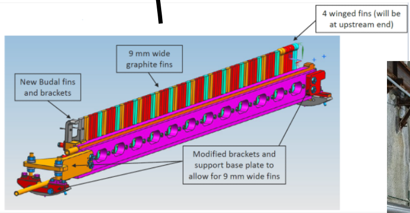
M. Lee
(Fermilab)

NuMI AIP (Accelerator Improvement Plan) and LBNF Beam Progress



Originally designed for 400 kW beam power, then upgraded to 700 kW

	NuMI Design	NOvA	1 MW upgrade
Proton beam energy	120 GeV		
Beam power (kW)	400 →	700 →	1 MW
Energy Spectrum	Low Energy	Medium Energy	
Cycle time (s)	1.87	1.33	1.2
Protons per spill	4.0×10^{13}	4.9×10^{13}	6.5×10^{13}
Spot Size (mm)	1.0	1.3	1.5
Beam pulse width	10 microsec		



- Record 893 kW in April 2022
- Upgrade for 1 MW through 2025

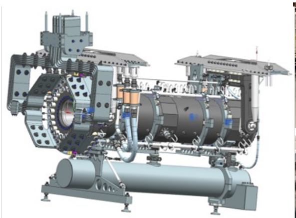
- 1 MW target installed in summer 2019
- Upgraded Horn 1 installed in summer 2020
- New 5x5 pixel monitor installed in summer 2021

LBNF: Designed for 1.2 MW (upgradeable to 2.4 MW)

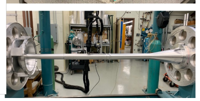
- Prototype Horn A undergoing fabrication/assembly
- Target design nearing final design stage. Prototyping

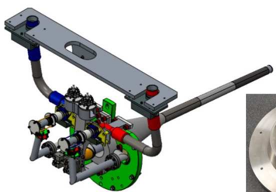
→ Many subsystems currently at 60-75% design maturity

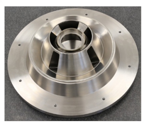
Parameter	Protons per cycle	Cycle Time (sec)	Beam Power (MW)
≤ 1.2 MW Operation - Current Maximum Value for LBNF			
Proton Beam Energy (GeV):			
60	7.5E+13	0.7	1.03
80	7.5E+13	0.9	1.07
120	7.5E+13	1.2	1.20
≤ 2.4 MW Operation - Planned Maximum Value for LBNF 2nd Phase			
Proton Beam Energy (GeV):			
60	1.5E+14	0.7	2.06
80	1.5E+14	0.9	2.14
120	1.5E+14	1.2	2.40



Horn A







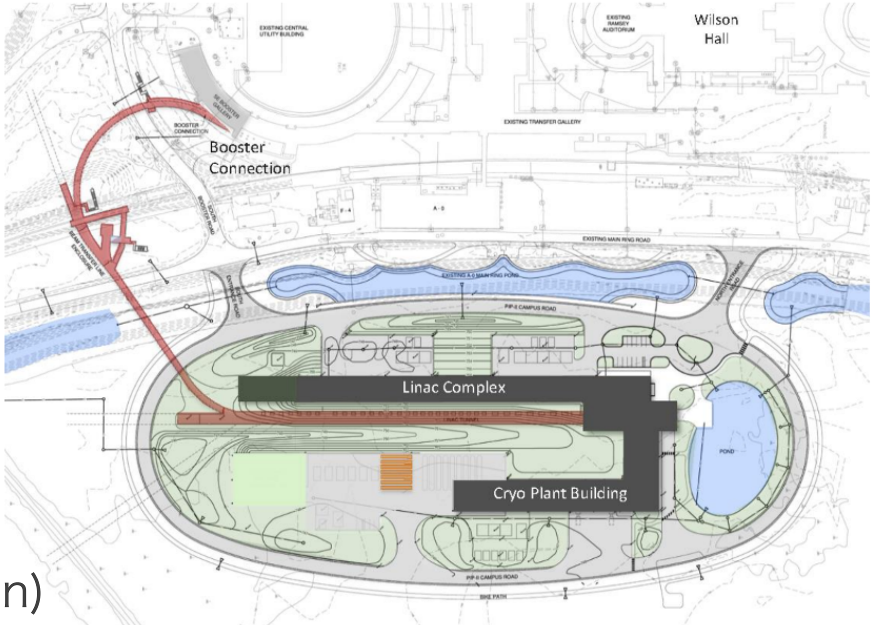
Titanium cross flow machined

2.4 MW Upgrade Paths for the Fermilab Accelerator Complex

J. Eldred (Fermilab)

PIP-II upgrade : 0.7MW → 1.2 MW

	PIP	PIP-II
MI Beamline	NuMI	LBNF
RR/MI Intensity	$54 \cdot 10^{12}$ protons	$65 \cdot 10^{12}$ protons
RR/MI Rep. Time	1.333 s	1.2 s
MI Power	0.7 MW	1.2 MW
Booster Intensity	$4.5 \cdot 10^{12}$ protons	$6.5 \cdot 10^{12}$ protons
Booster Rep. Rate	15 Hz	20 Hz
Booster Ext. Power	85 kW	165 kW
Injection Energy	0.4 GeV	0.8 GeV
Efficiency	95%	98%

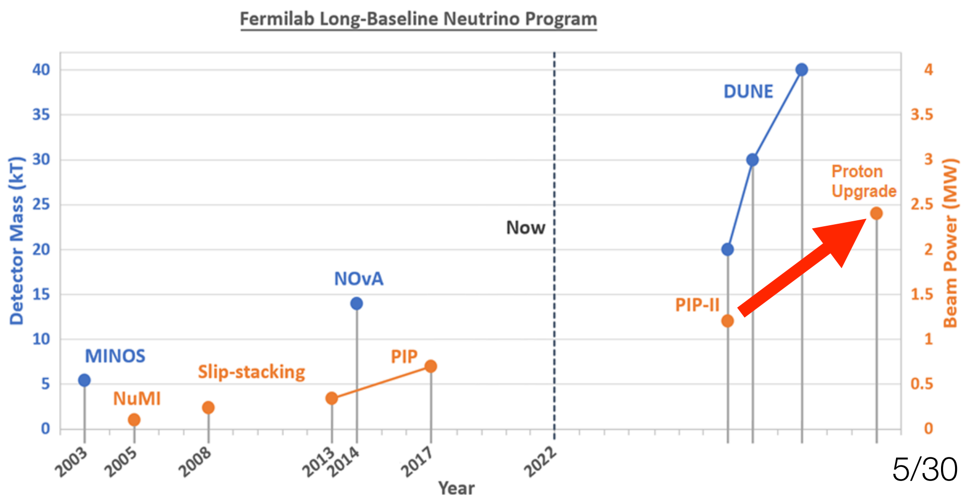


Project started in 2016 (CD0)
First beam in Booster: 2028 (plan)
MI 1.2 MW beam on target: 2032 (projection)

Strategic planning for 2.4 MW were reported

- ICD-2 RCS: Well-developed cost-effective proposal, focused on LBNF
- BSR RCS: More challenging injection, more 8-GeV power.
- 8-Gev Linac: Most challenging injection, highest 8-GeV potential

Cost and timetable evaluations underway



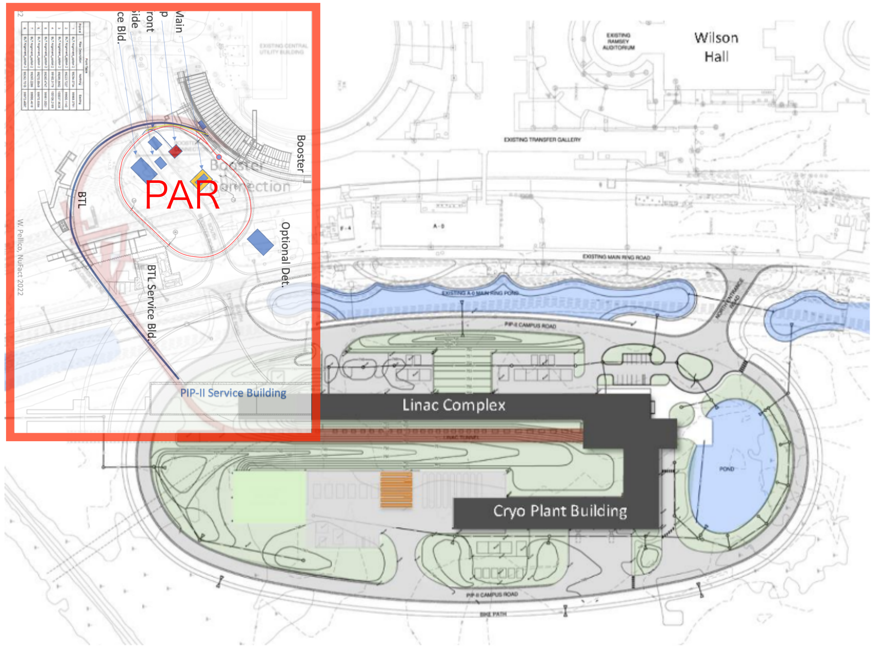
W. Pellico
(Fermilab)

PIP-II Accumulator Ring - PAR

A storage ring option for a modest cost & within this decade,

Present
Linac:
15 Hz. 30 ma
Booster:
8 GeV,
15 Hz

PIP-II complex & PAR
SRF PIPII: 800 MeV:
2.5 ma, High Cycle Rate
Upgradable
PAR:
100Hz (Upgradable)
800 MeV (Upgradable)
Booster:
8 GeV, 20 Hz



PAR status & prospects

- The effort for PAR started almost two years ago
  - Originally located in the Booster Tunnel was called BAR
- Opted to move adjacent to the Booster near the PIP-II injection line BTL
  - Civil cost higher, Reduced impact to Booster, No impact to present PIP-II Booster plan
- Finishing up lattice and beam physics in 2022
- Cost estimates will be provided in early 2023
- Complete interface of PAR with BTL civil plans 2023

→ if we can get the cost to a reasonable number – PAR will be done!

First results of the high repetition operation in J-PARC MR

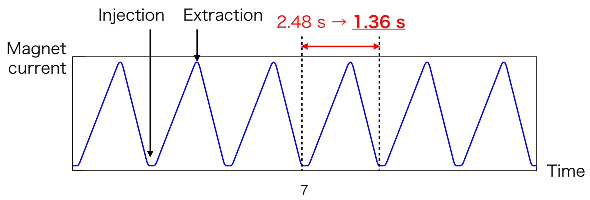
T. Yasui
(KEK/J-PARC)

Beam upgrade to 1.3 MW w/ increased protons & faster cycle

Power = Energy × Number of protons / Cycle time

Energy: 30 GeV

	Power	Number of protons	Cycle time
JFY2021	515 kW	2.66×10^{14} ppp	2.48 s
JFY2023	750 kW	2.1×10^{14} ppp	1.36 s
Future	1300 kW	3.3×10^{14} ppp	1.16 s

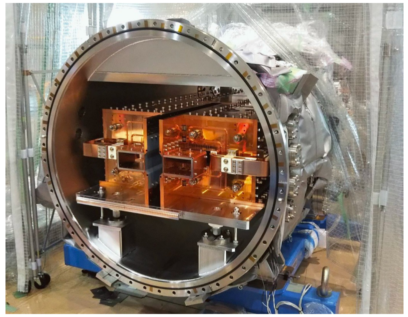


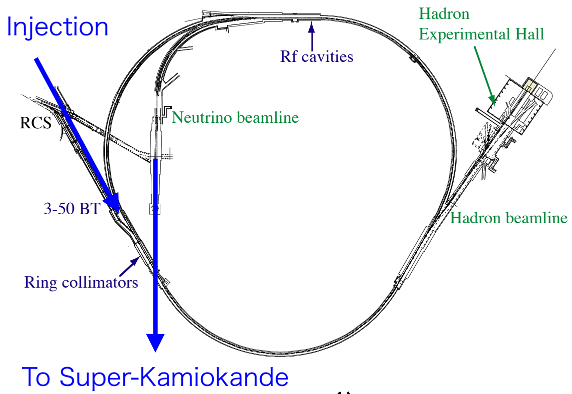
Hardware upgrade
1) Power supplies of main magnet
2) RF system
3) FX septum magnet
4) Collimator system

1)

	Family label	Num of family	Num of magnets	Strategy
Bends	BM	6	16 each	New PSs with capacitor bank
Quadrupoles in arc sections	QFN	1	48	
	QDN	1	48	
	QFX	1 → 2	48 → 24 each	Reuse of present PSs (Family divided)
	QDX	1 → 2	27 → 13+14	
Quadrupoles in straight sections	QFS	1 → 2	6 → 3 each	
	QDS	1 → 2	6 → 3 each	
	QFT	1 → 2	6 → 3 each	
	QFP	1	6	Reuse of present PSs
	QFR	1	9	
	QDT	1	6	New PSs without capacitor bank
	QDR	1	6	
Sextupoles	SFA	1	24	
	SDA, SDB	2 → 1	24+24 → 48	

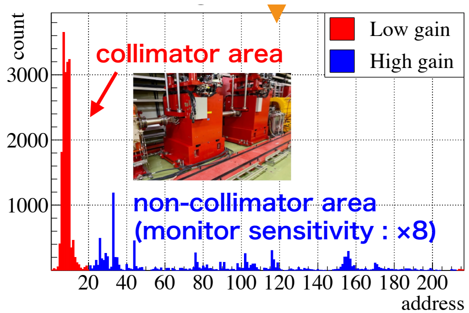
3)





2)

4)

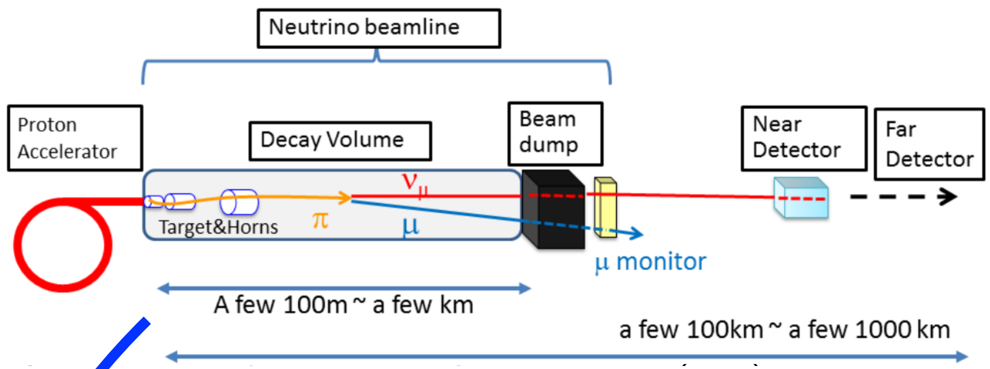


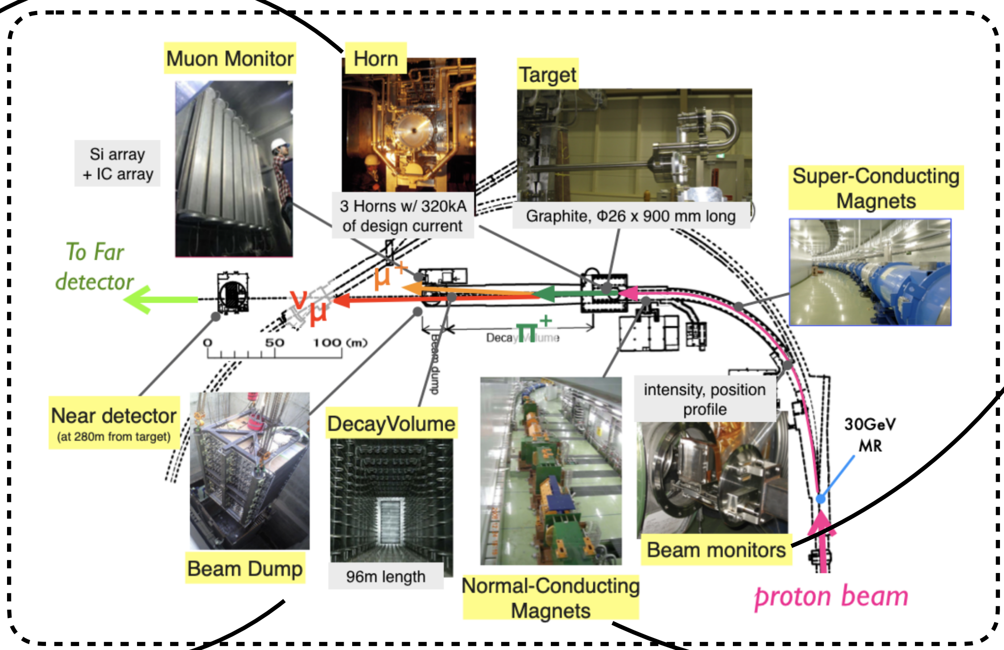
- Upgraded hardwares are verified by beam study in June w/ 1.36s cycling period

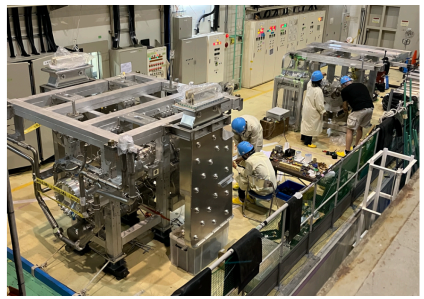
M. Friend
(KEK/J-PARC)

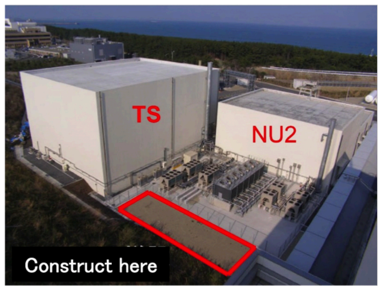
J-PARC Neutrino Beam Upgrade

- Now underway for T2K & toward HK
- Many progress were reported
  - Primary beamline for better handing
  - DAQ, Beam control, Interlock
  - Monitors like OTR, WSEM, BIF, EMT
  - Horns & target cooling system
  - Radioactive water disposal



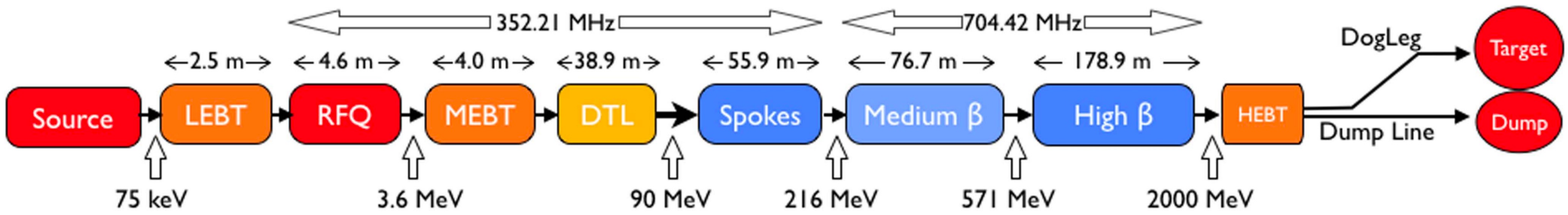






ESS linac status and NC linac commissioning

R. Miyamoto (ESS)



- European Spallation source (ESS) is
  - Under construction in Lund, Sweden
  - Driven by a high-power proton linac

- Milestones of the first beams
  - Through RFQ, 2021-11-26
  - Nominal current beam up to MEBT, 2022-03-12
  - Through DTL1, 2022-06-01
  - Nominal current out of DTL1, 2022-07-01

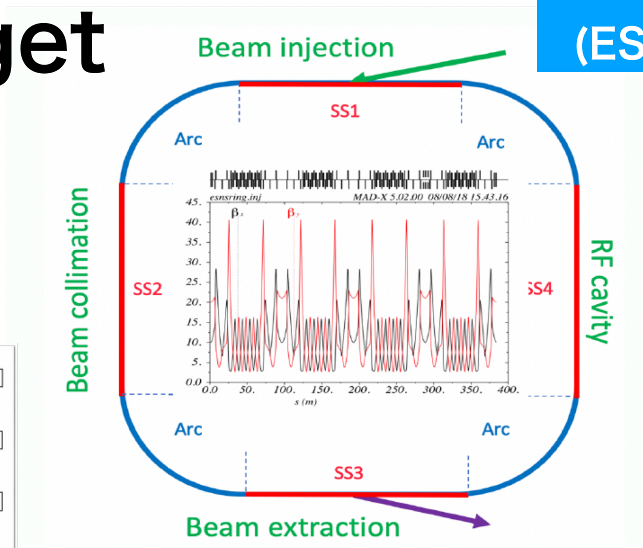
- Detailed commissioning status were reported.
  - Peak performance of hardware is good so far.

ESSnuSB from source to target and plans for the future

N. Milas (ESS)

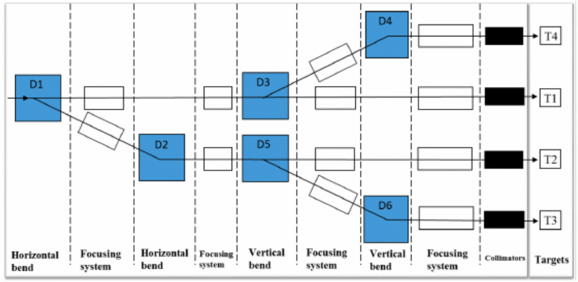
The latest design were reported

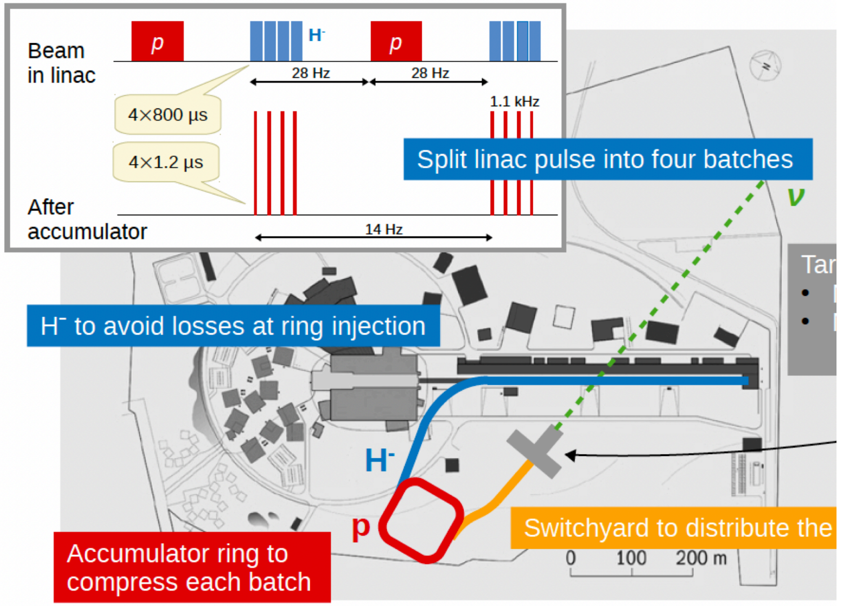
- Accumulator Ring Design
- Switchyard Design
- Target design

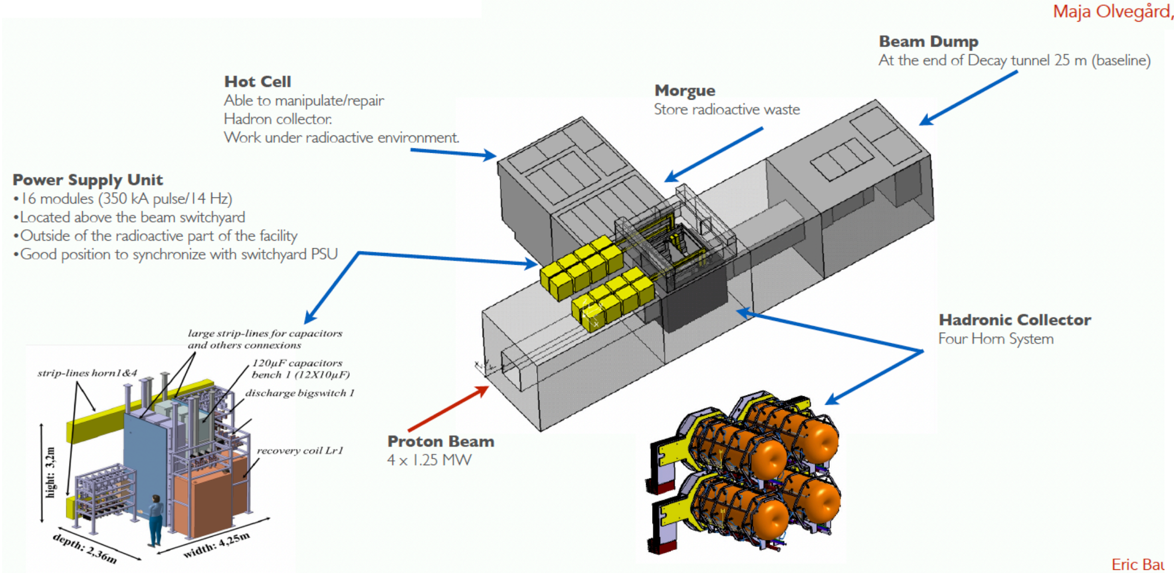


	ESSnuSB	PSB	SNS	J-PARC RCS
Ring circumference	384 m	157 m	248 m	348 m
Beam energy at injection	2.5 GeV	160 MeV	1.0 GeV	400 MeV
Beam energy at extraction	2.5 GeV	2.0 MeV	1.0 GeV	3.0 GeV
Number of injected particles	2.3e14	1.6E13	1.5E14	8.3E13

Maja Olvegård, Ye Zo







- Further important studies needed before start ESSnuSB construction
- Multi purpose facility with great potential will be pursued
  e.g. Low Energy nu STORM, ENUBET

Material studies & beam diagnosis for high power bam

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

Program manager: Dr. Frederique Pellemoine (FNAL)

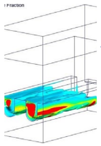
Future Collaborators

F. Pellemoine (Fermilab)

Advanced Materials Studies for HI Proton Production Targets and Windows

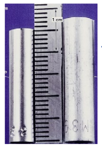
- Materials R&D essential to help design robust targetry components and maximize primary beam power on target and secondary particle production
  - Globally coordinated R&D activities are producing useful results

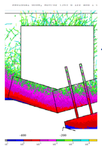
High Power Targetry Challenges


Heat removal


Thermal shock


Physics performance


Radiation damage


Operational safety


Storage and disposal

Research Approach - Prototypic irradiation to closely replicate material behavior in accelerator target facilities

- High-energy proton irradiation of material specimens at BNL-BLIP facility in partnership with the RaDIATE collaboration
  - 1st irradiation campaign completed in 2017/2018, 2nd irradiation planned in 2024-2025
- Post-Irradiation Examination (PIE) conducted at participating institution equipped with hot-cell facilities (PNNL)
- In-beam thermal shock experiment at CERN's HiRadMat facility that includes both pre-irradiated (BLIP) and non-irradiated specimens
  - Completed experiments in 2015 and 2018. Currently preparing for upcoming test in Oct. 2022

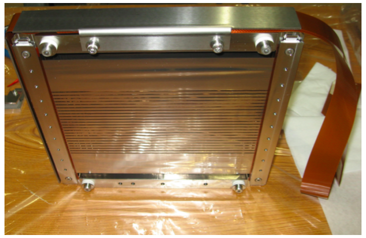
- Many ongoing efforts were reviewed in the talk
- Exploring novel targetry materials: Electrospun nanofibers and High-Entropy Alloy

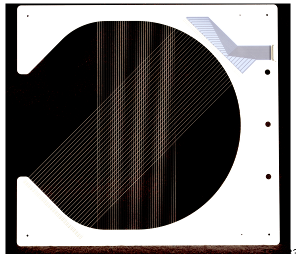
Proton Beam Monitor Upgrades for the J-PARC Neutrino Extraction Beamline

M. Friend
(KEK/J-PARC)

Beam profile must be monitored continuously for beam diagnostics and tuning
- To correctly steer the proton beam/protect beamline equipment
- To be used as input into neutrino flux prediction simulation

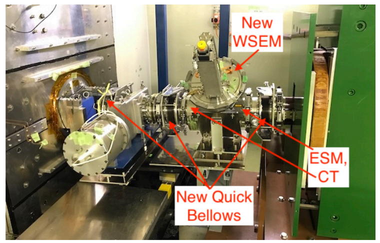
- Wire Segmented Emission Monitor (WSEM)
  - Reduced beam loss (~1/10)
  - Work stably since 2018
  - New WSEM installed soon



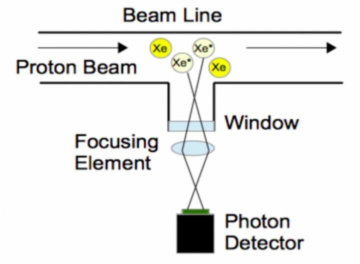


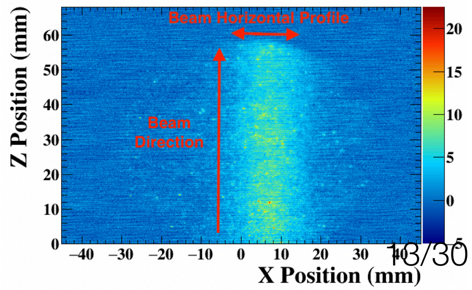
- Optical radiation monitor (OTR)
  - New OTR installation in 2022
  - Tests in Feb./Mar.

- Better handling to reduce radiation dose
  - Make space for quick, hands-on maintenance
  - New magnet installed in summer 2021



- Beam Induced Fluorescence Monitor (BIF)
  - Non-destructive robust monitor
  - Full prototype test in 2020/2021
  - Upgrade to working prototype in 2022

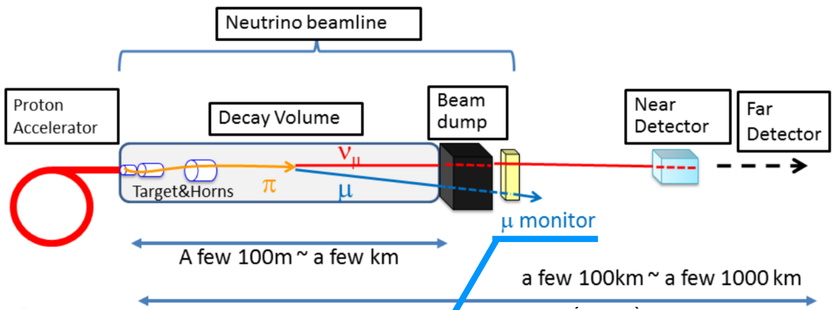


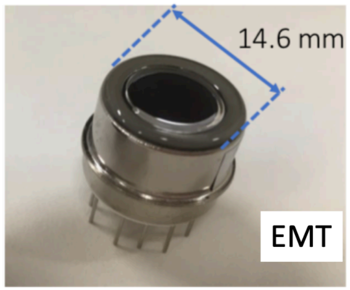


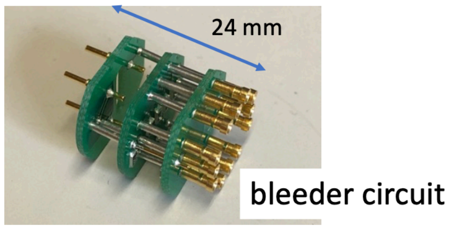
New muon monitor for J-PARC neutrino experiment

T. Honjo
(Osaka Metro. U.)

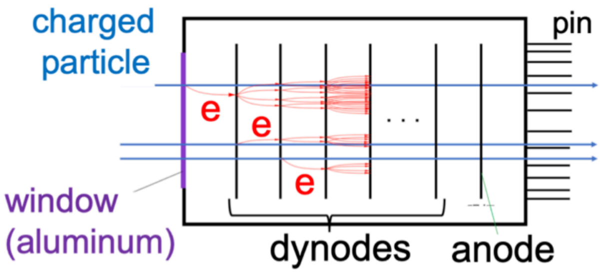
- New sensor (EMT) w/ more rad. tolerance
  - PMT photocathode → Al deposited glass

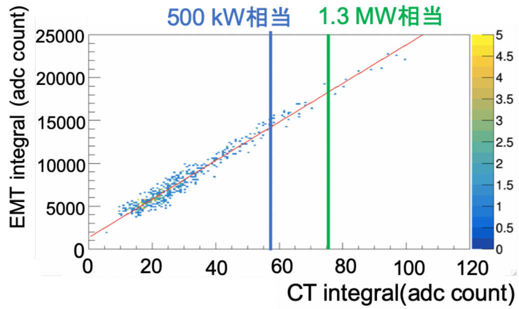


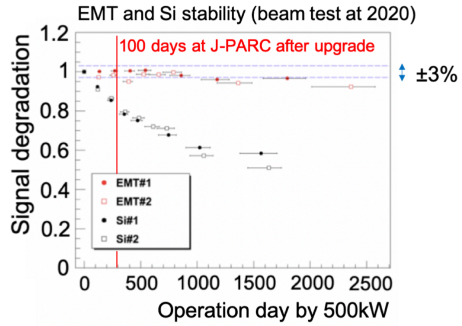




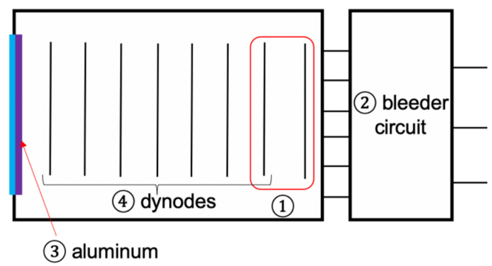
Bleeder circuit is made of as little resin as possible.

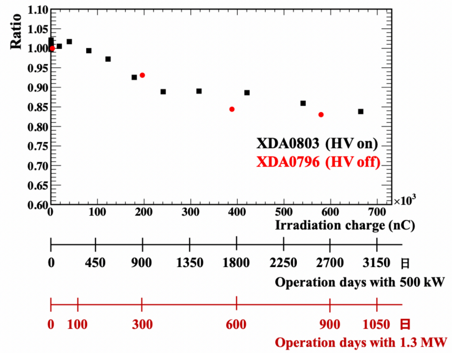






- Confirmed linearity & radiation tolerance @ First/second beam test

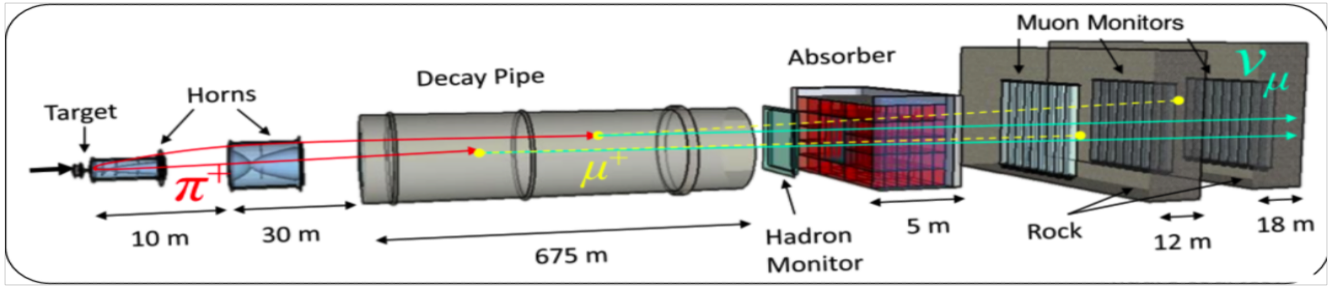


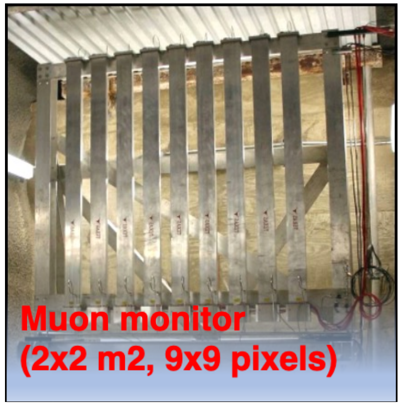


- Progress of investigating cause of the radiation damage @ third beam test
- Further beam test to complete the investigations for life-time extension

Yiding Yu
(IIT)

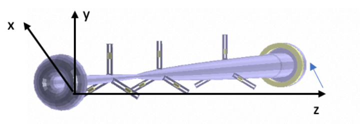
NuMI Beam Monitoring Simulation and Data Analysis

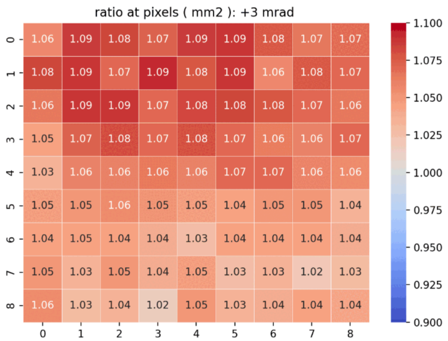




Simulation study about the effect of pixels of MMs

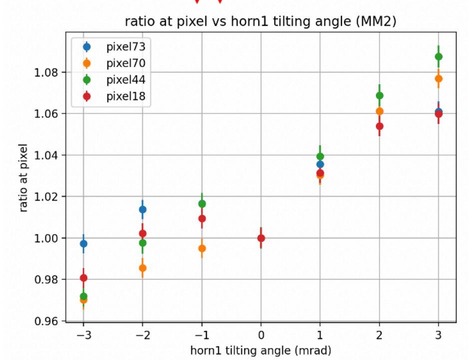
Horn1 tilt angle(x axis) effect





Top pixel are more sensitive to the change

33	42	51	60	69	78	6	15	24
34	43	52	61	70	79	7	16	25
35	44	53	62	71	80	8	17	26
36	45	54	63	72	0	9	18	27
37	46	55	64	73	1	10	19	28
38	47	56	65	74	2	11	20	29
39	48	57	66	75	3	12	21	30
40	49	58	67	76	4	13	22	31
41	50	59	68	77	5	14	23	32



Beam parameter	change	MM1	MM2	MM3
Horn1 tilt angle Y	± 3 mrad	✕	O	O
Horn1 tilt angle Y	± 2 mrad	✕	O	O
Horn1 tilt angle Y	± 1 mrad	✕	O	✕
Target offset Y	± 1 mm	O	O	O
Target offset Y	± 0.5 mm	O	O	O
Target offset Y	± 0.1 mm	O	✕	✕
Target density	- 1%	✕	✕	✕
Horn1 position Y	± 1 mm	✕	O	O
Horn current	± 1 kA	O	O	O
Magnetic field in decay pipe	No and twice	O	O	✕

O: difference is over 3 sigma at some pixels

✕: difference is within 3 sigma

08/04/22 Yiding Yu | Nufact 2022 24

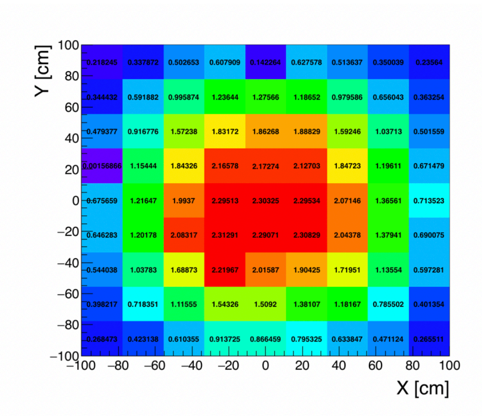
Confirmed monitoring capabilities to find the effect of varying the beam parameters

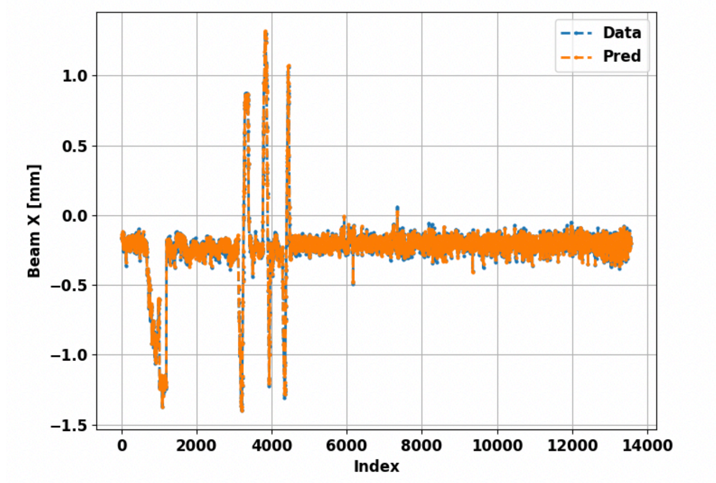
Machine Learning Applications to Maintain the NuMI Neutrino Beam Quality

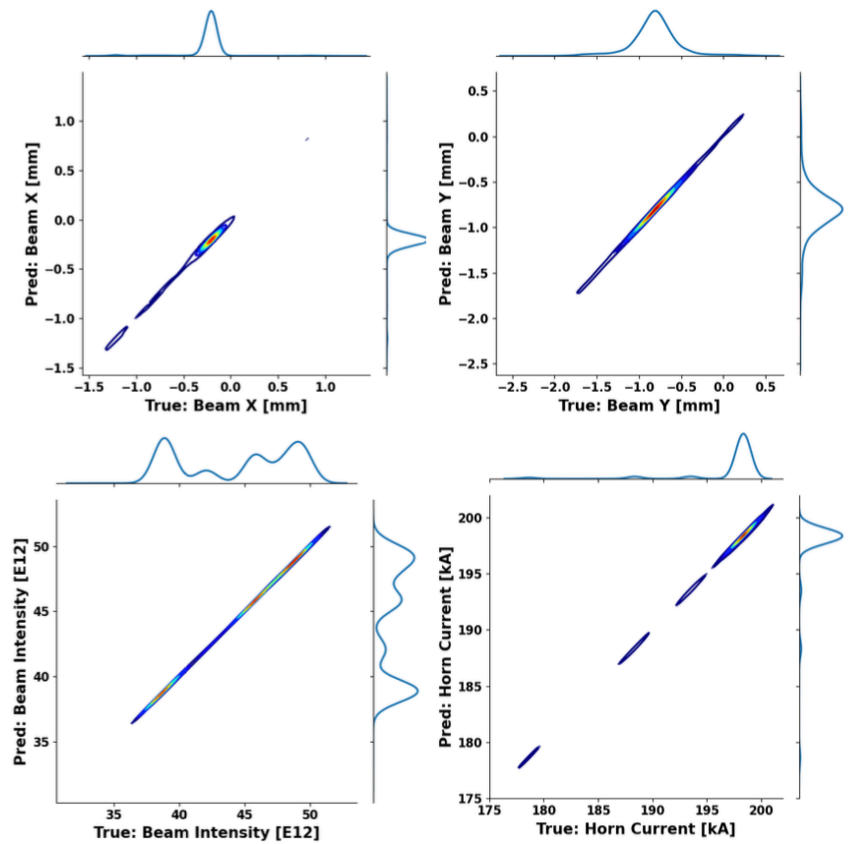
A. Wickremasinghe (Fermilab)

- Promising results to use the model as a monitoring tool in the future

- Randomly sampled training (70%) and validation (30%) data samples were selected from the target scans and normal operations
- A neural network has been trained by taking account 241 pixels as inputs







- Testing and validating the use of simulation data to build ML applications are in progress
  - To understand correlations b/w muon monitor data & neutrino flux at ND
  - To help catch “anomaly” scenarios; e.g. horn tilt/slip, target tilt, target deterioration, etc…

Muon collider/Neutrino factory

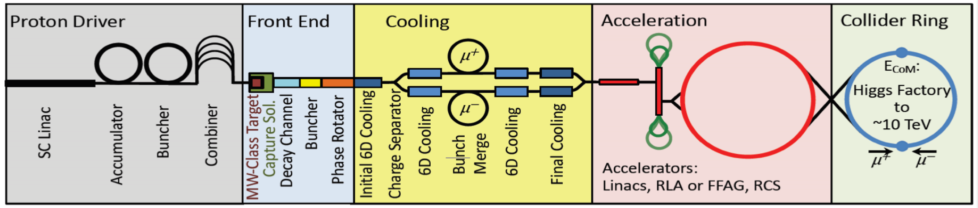
International MUON Collider Collaboration

MICE

νSTORM

D. Schulte (CERN)

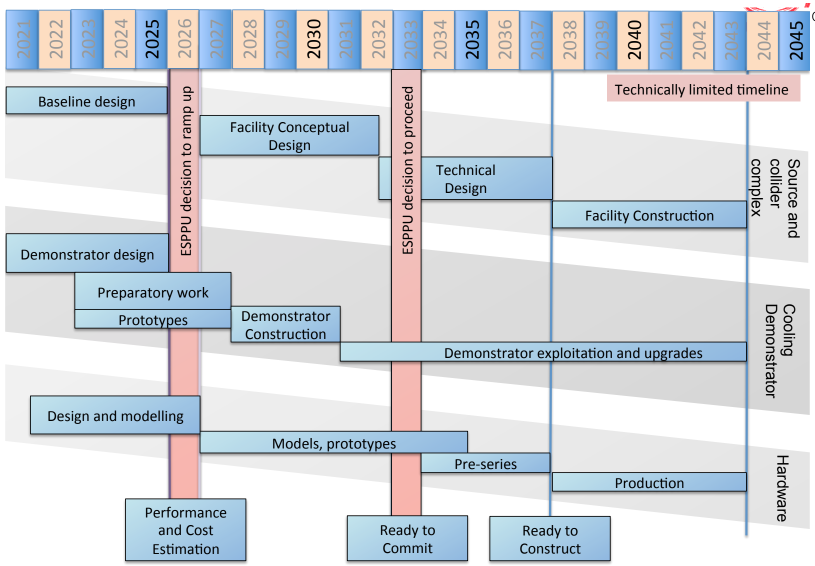
Muon Collider



Previous studies in US (now very strong interest again), experimental programme in UK and alternatives studies by INFN

New strong interest:

- Focus on high energy with high luminosity
  - 10+ TeV
  - potential initial energy stage (e.g. 3 TeV)
- Technology and design advances
- Combines precision physics and discovery reach



EU Design Study

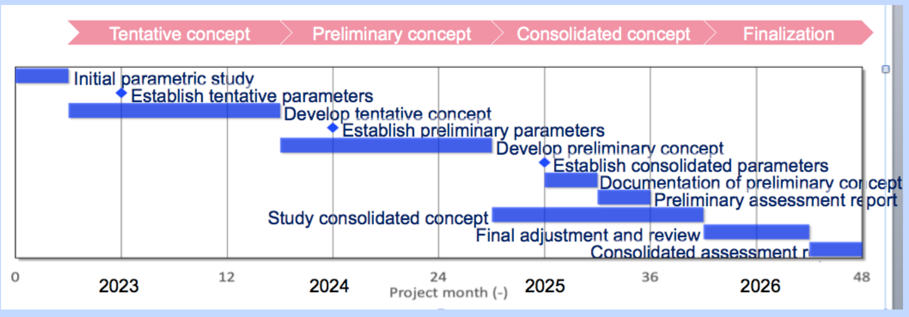
HORIZON-INFRA-2022-DEV-01-01: Research infrastructure concept development
Expected EU contribution: 1-3 MEUR,
Total budget 21.8 MEUR
Type of Action: Research and Innovation Actions

Workpackages

1. Coordination and Communication
2. Physics/Detector Performance Requirements
3. Proton Complex

Approved last week, now preparing contract
EU contribution 3 MEUR, partners 4 MEUR, CERN

International MUON Collider Collaboration



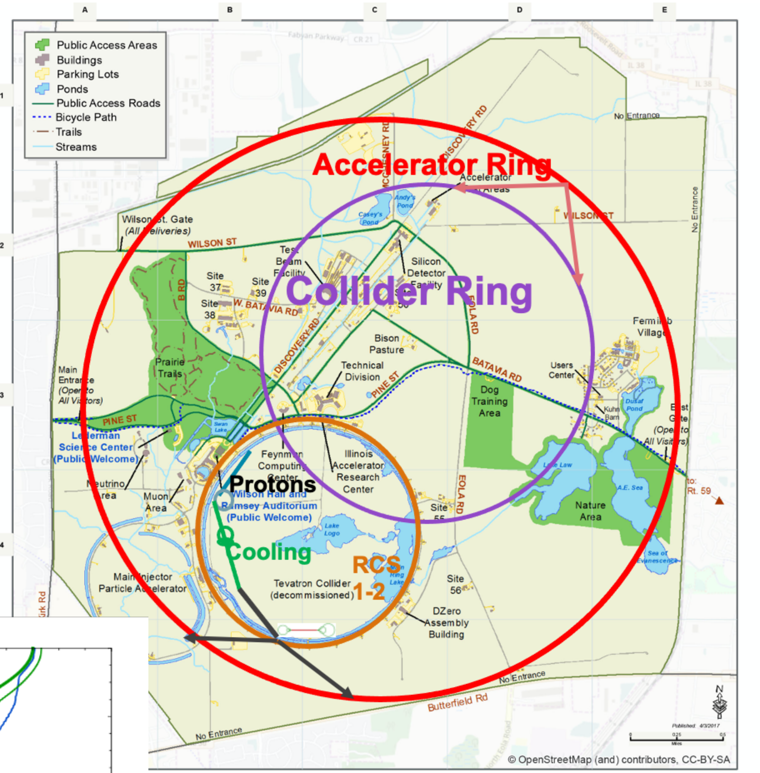
Discussed roadmap, recent progresses, …

D. Neuffer
(Fermilab)

A Muon Collider at Fermilab

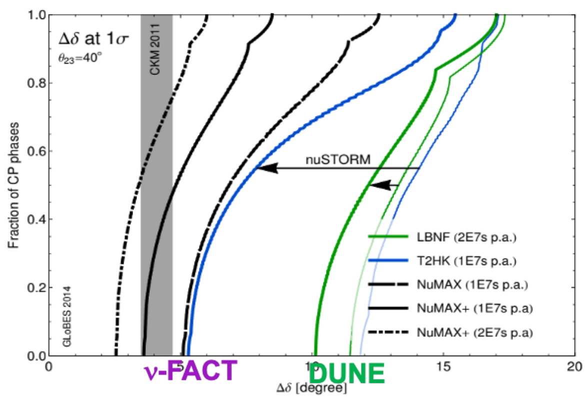
Fermilab site filler: Muon Collider up to ~10 TeV

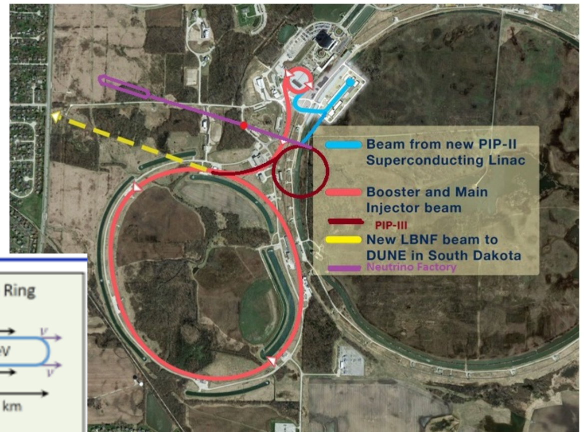
- Proton Source : PIP-III → Target
- μ cooling
- Linac + RLA → 65 GeV
- RCS 1 and 2 → 1000 GeV
  - Tevatron-size
- RCS 3 → 5 TeV
  - Site filler accelerator
- Collider Ring ~10 km

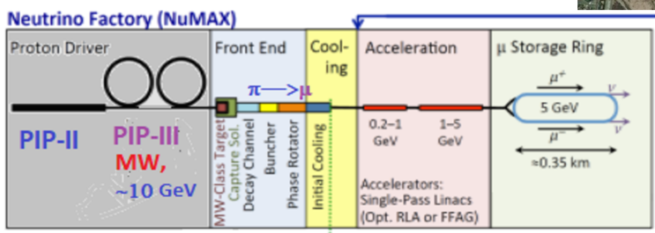


Fermilab PIP-III Neutrino options

- DUNE → ???
  - PIP-III
- Muon-based beams
  - Short BL (nuSTORM)
  - Long BL (DUNE)
  - ~4 GeV μ storage ring







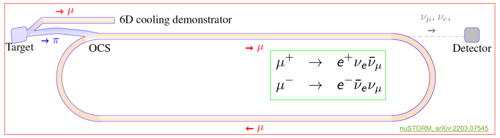
Progress of studies on the Neutrinos from Stored Muons, nuSTORM, facility

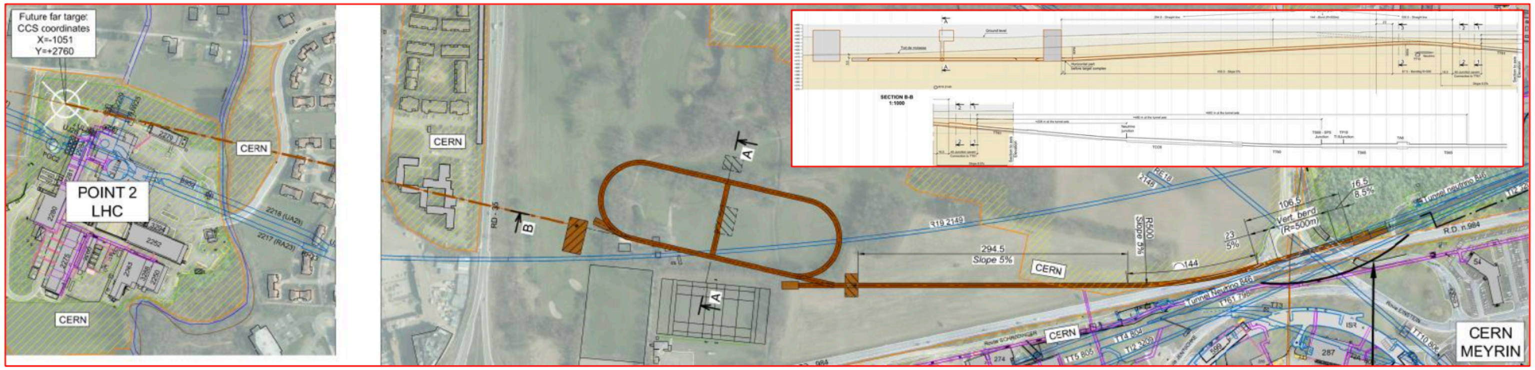
J. Pasternak
(Imperial C./RAL)

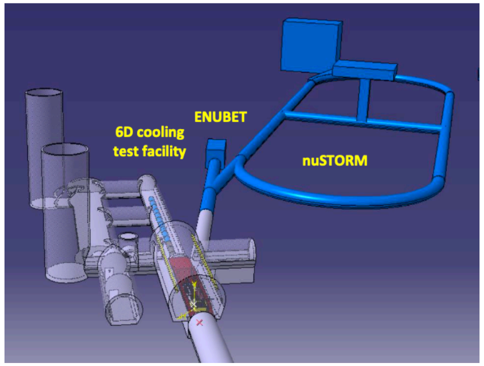
- nuSTORM can measure neutrino interaction precisely
  - Reduced systematic errors for CPV and sterile neutrino search
  - Can also serve as the R&D test bed for muon accelerators

- Technologies for muon storage, 6D cooling, parametric cooling or rapid muon acceleration (vertical FFA) can be tested experimentally

- nuSTORM at CERN: Extraction from SPS through existing tunnel





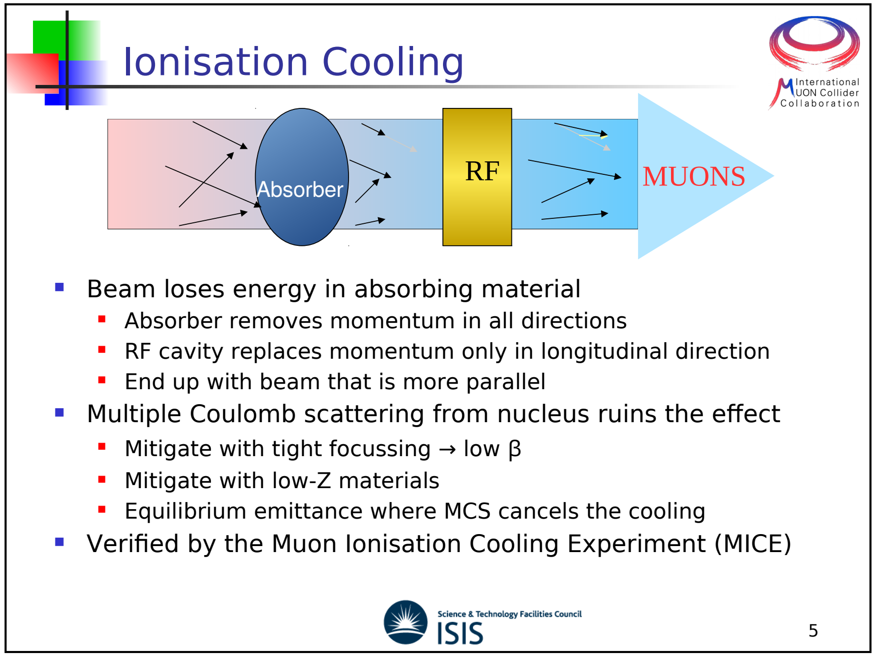


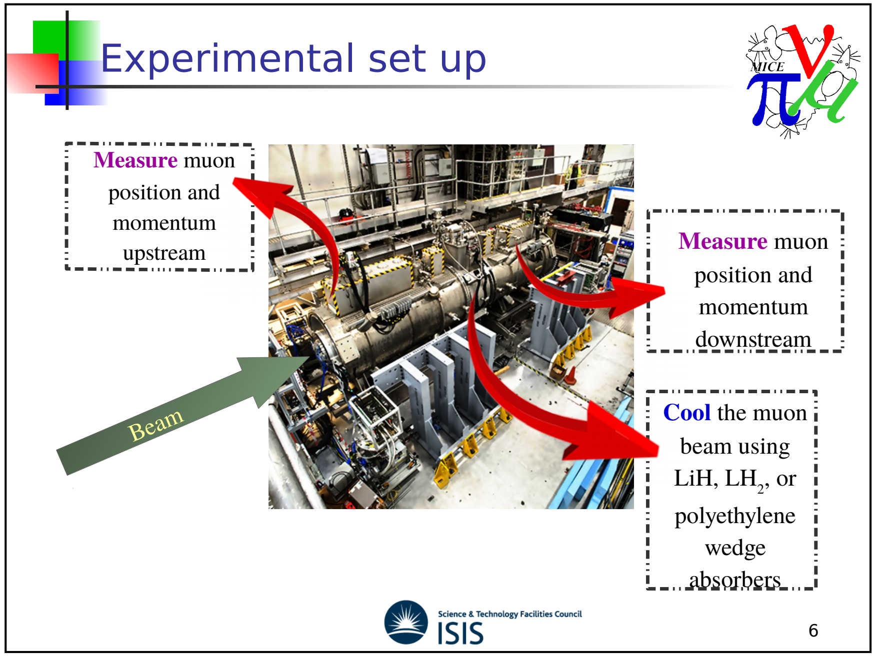
- Solid designs exist and could be implemented straightaway (FODO or FFA)
- Novel Hybrid ring shows very promising results. Working to demonstrate its performance.
- New ideas to combine nuSTORM, ENUBET and Muon Test Facility
- Promising recent progress on pion capture, transport and injection

Characterization of Cooling in the Muon Ionization Cooling Experiment

C. Rogers (ISIS)

- High-brightness muon source needed for Muon collider
  - Beam needs to be cooled using ionisation cooling
- MICE built to study muon cooling
  - Unprecedented single particle measurement of particle trajectories in an accelerator lattice





- MICE has made first observation of ionization cooling
- Significant interest in a follow-up experiment
- Longitudinal and transverse emittance reduction. Explore lower emittances

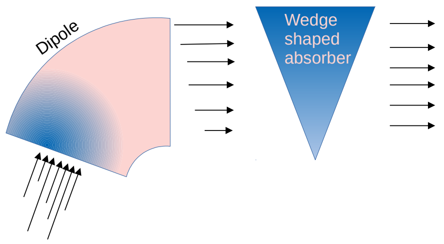
C. Rogers (ISIS)

A Demonstrator for Muon Cooling

- Transverse cooling at high emittance demonstrated by MICE

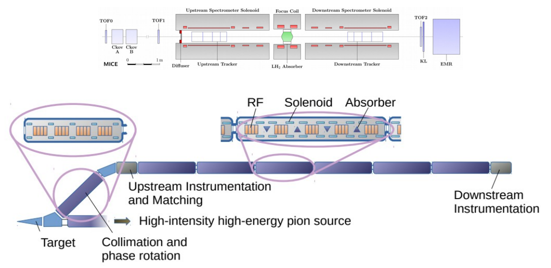
→ Now need to follow up with 6D cooling at lower emittance
  - What could such a Demonstrator look like?
  - Where could it be sited?

6D Ionisation Cooling



- Initial beam is narrow with some momentum spread
  - Low transverse emittance and high longitudinal emittance
- Beam follows curved trajectory in dipole
  - Higher momentum particles have higher radius trajectory
  - Beam leaves dipole wider with energy-position correlation
- Beam goes through wedge shaped absorber
  - Beam leaves wider without energy-position correlation
  - High transverse emittance and low longitudinal emittance
- Tests done at Fermilab

Comparison with MICE



	MICE	Demonstrator
Cooling type	4D cooling	6D cooling
Absorber #	Single absorber	Many absorbers
Cooling cell	Cooling cell section	Many cooling cells
Acceleration	No reacceleration	Reacceleration
Beam	Single particle	Bunched beam
Instrumentation	HEP-style	Multiparticle-style

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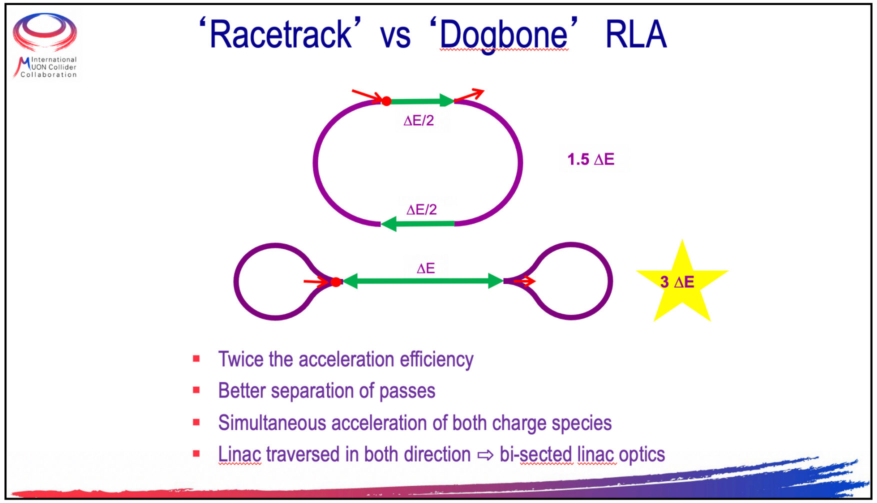
- Demonstrator lattice proposed. Beam preparation system considered. Optimisation and further studies ongoing → Compatible with nuSTORM
- Aim is to deliver a design by 2026 → In time for next European strategy update

Muon Acceleration for Future Neutrino and Higgs Factory

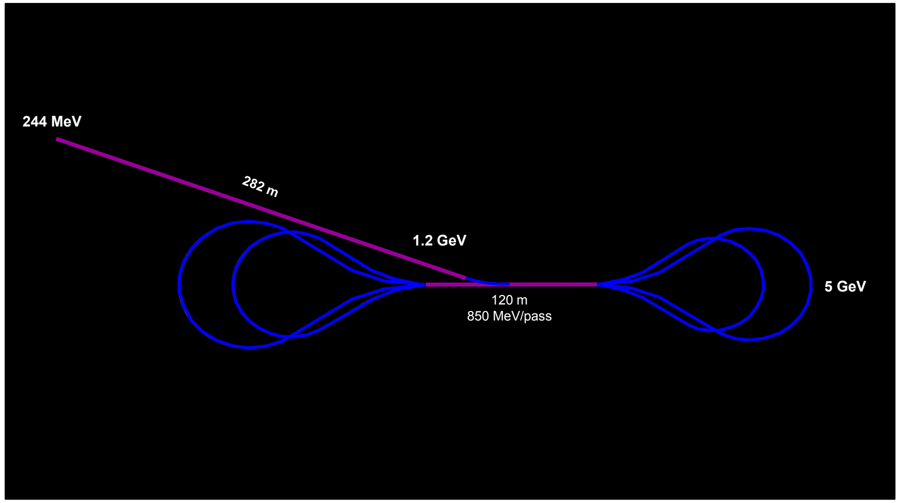
A. Bogacz (Jefferson Lab)

Muon Acceleration - Choice of Technology

- Acceleration of short-lived muons requires high average gradient
- Recirculation (RLA) provides significant cost savings
- A single linac at low energy since the beam is not sufficiently relativistic



Linac + Recirculating Linear Accelerator (RLA)

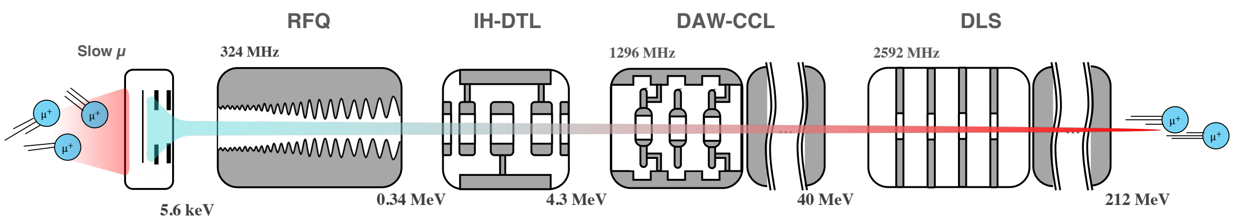


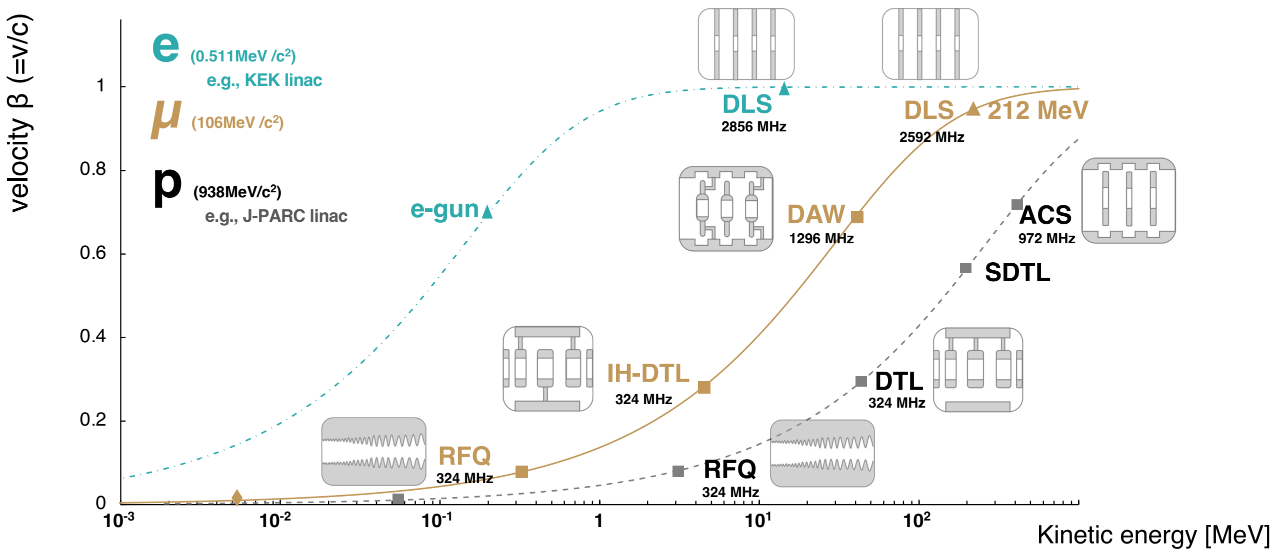
- RF system specs for low energy acceleration stages:
  - Linac (255 MeV - 1.25 GeV) 1-pass
  - RLA 1 (1.25 - 5 GeV) 4.5-pass
  - RLA 2 (5 - 63 GeV) 5-pass
- Next step : Optimized Linac + RLAs scheme for Higgs Factory and beyond…

Y. Nakazawa
(Ibaraki U.)

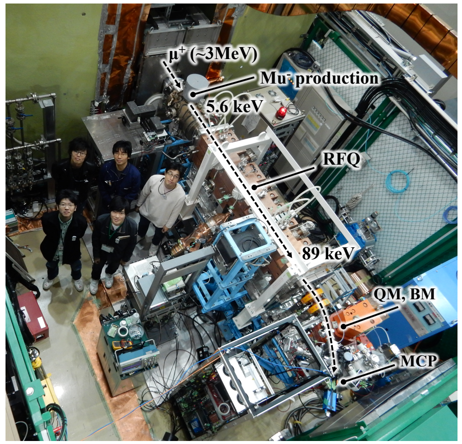
Muon Acceleration for the muon g-2/EDM experiment at J-PARC

- Developing the muon linac for the muon g-2/EDM experiment





Frequency	324MHz, 1296MHz, 2592 MHz
Intensity	1×10^6 /s
Rep rate	25 Hz
Pulse width	10 ns
Norm. rms emittance	1.5 π mm mrad
Momentum spread	0.1 %



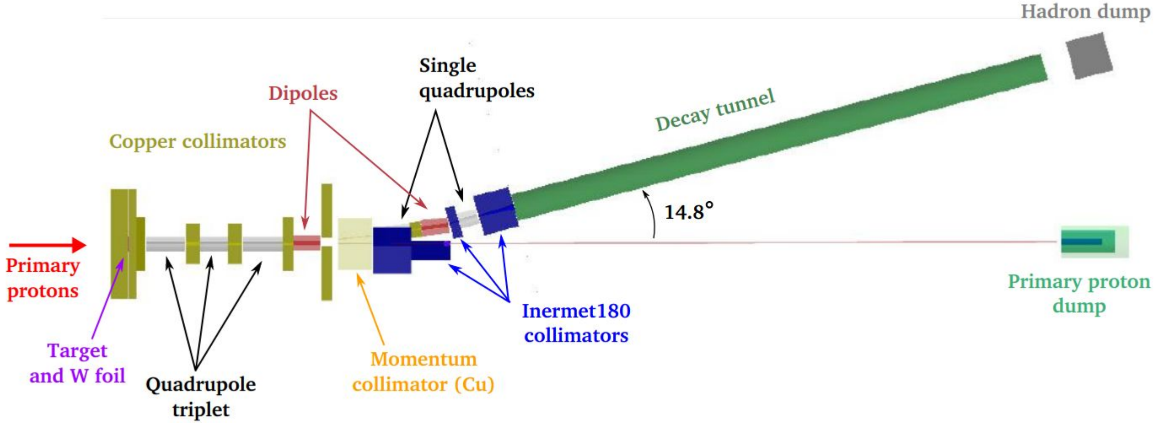
- The world's first muon RF acceleration to 0.34 MeV (Nov. 2017)
- Next step : μ+ acceleration w/ RFQ-IH-DTL. (2024)

Other unique beam facilities

E.Parozzi (CERN)

The design of the ENUBET beamline

Fully static Beamline → Slow extraction of a few seconds required by pile up constraints
Transfer line optimized for 8.5 GeV/c secondaries
optics design: TRANSPORT
tracking & background: G4Beamline/G4
doses & neutron shielding: FLUKA
systematics: GEANT4



- Target: 70 cm graphite rod w/ 6 cm d
- Magnets:
  - normal conducting quad & dipoles
  - two 1.8 T dipoles for 14.8 deg total bending angle
- Decay tunnel:
  - length of 40 m w/ 1 m radius
  - borated PE shielding
- Dumps:
  - 3 cylindrical layers proton dump
  - same structure for hadron dump (reduced backscattering flux)

Reported :

- Monte Carlo simulations to predict beamline performance
- Optimizations of beam line configurations
- Multi-momentum beam line designed with existing CERN Magnets and full G4BL

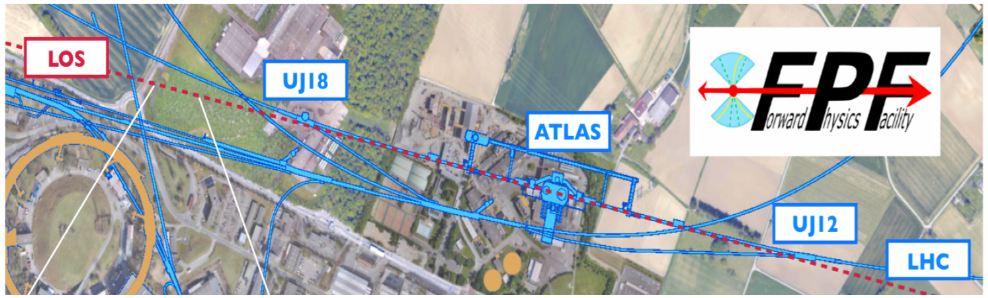
Next steps :

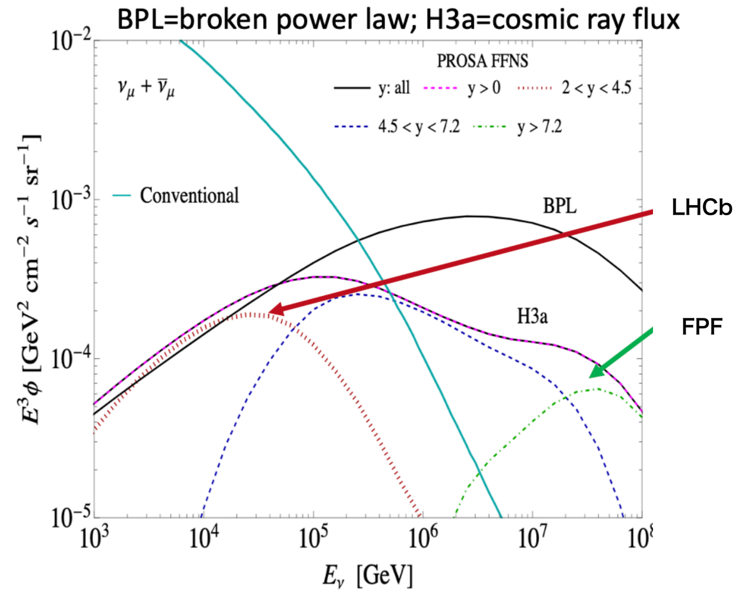
- 1% level on flux achieved w/ Baseline Beamline option → MMB to be validated.
- Beamline instrumentation studies, Radiation studies with FLUKA → Ongoing

I. Sarcevic
(U. Arizona)

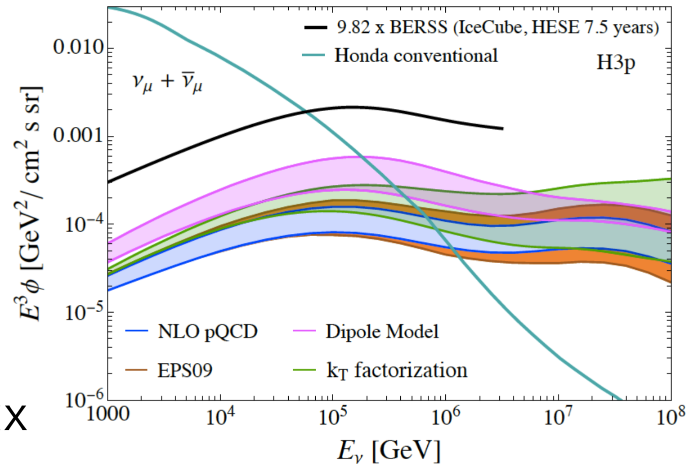
Forward Neutrinos from Charm at the LHC and Prompt Neutrinos at IceCube

- FPF experiments will detect about 1M ν interactions (1K ν_τ) with energies up to a few TeV
- ν_τ produced in the forward region, come from the decay of charmed mesons.





- Prompt neutrinos
  - From decay of heavy quarks (c or b) before losing much energy → Neutrino energy spectrum is harder
- Connection to forward neutrino production at HL-LHC, i.e. measurements with FASER can reduce theoretical uncertainties in the prediction of the prompt neutrino flux



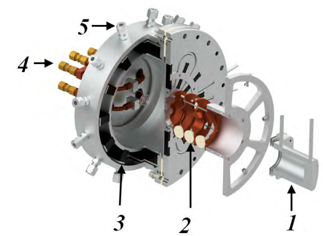
- Important to pursue Forward Physics Facility Program and Neutrinos telescopes

D. Winklehner (MIT)

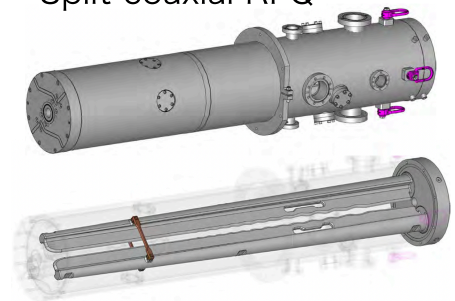
IsoDAR@Yemilab - A definitive search for exotic neutrinos and other BSM physics

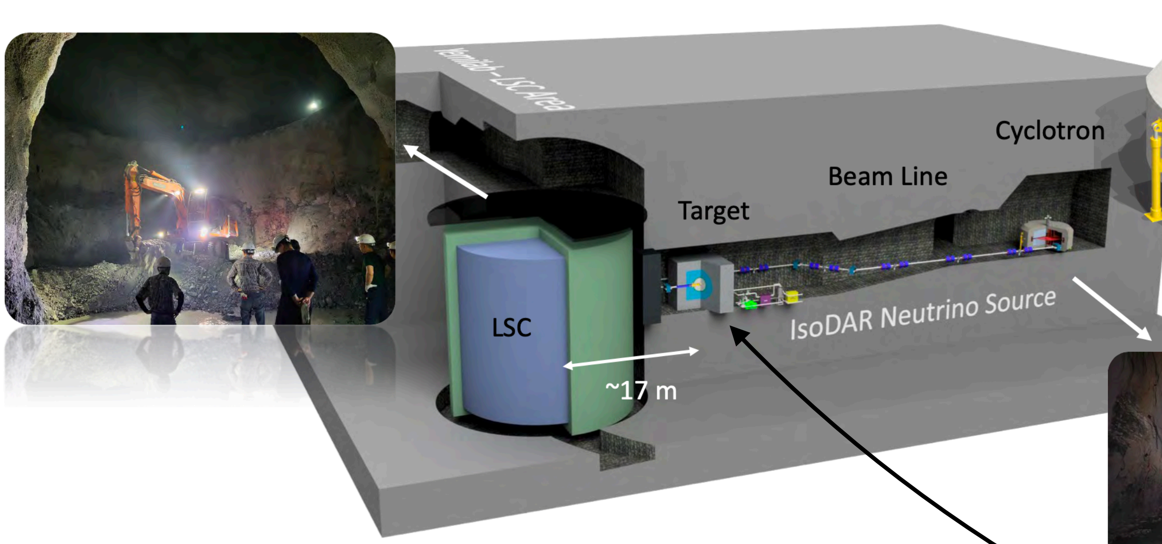
- Search for noble (sterile) neutrinos through oscillations at short distances and low energy at Underground facility at Mt. Yemi in Korea.
- Possible application of isotopes for consortia of hospitals

H_2^+ ion source

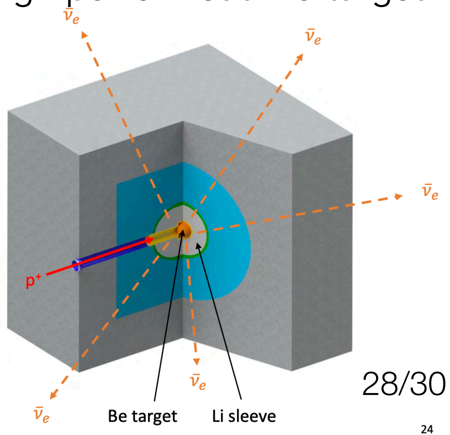


Split-coaxial RFQ





High power neutrino target



- Caverns are already constructed
- Testing Hardware prototypes (injector, target)
- Writing Proposals for full accelerator & detector
- Planning for 2027 – 2032 run

MELODY at CSNS-II

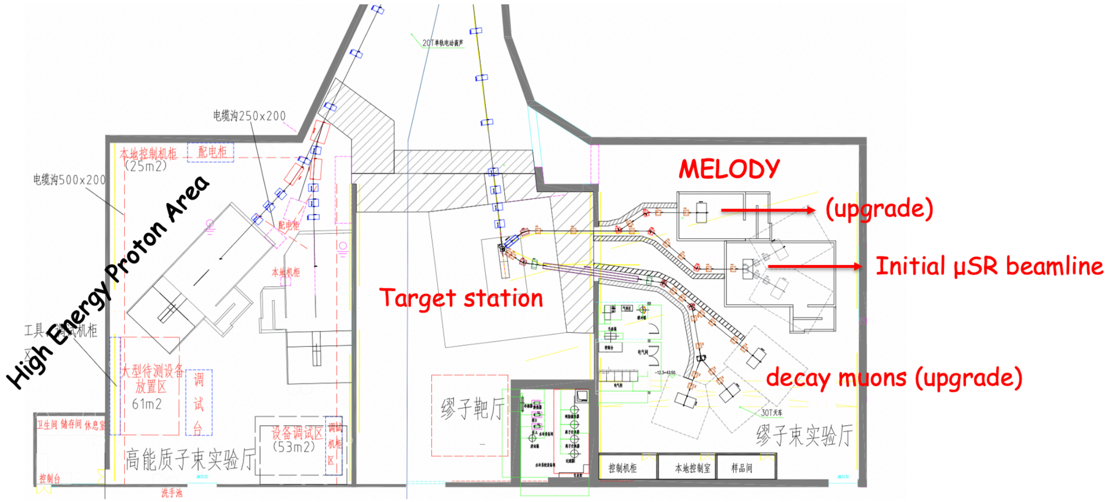
N. Vassilopoulos
(IHEP)

- First muon source in China at CSNS

Parameters	CSNS-I	CSNS-II
Beam power (kW)	100	500
Linac Energy (GeV)	0.08	0.3
RCS Energy (GeV)	1.6	1.6
Beam current (μA)	62.5	312.5
Repetition rate (Hz)	25	25

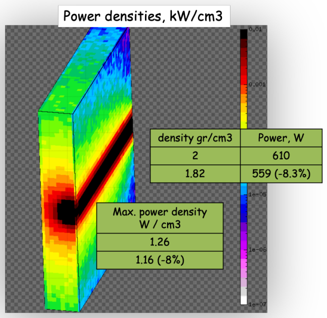
MELODY: Layout @ CSNS-II

a) Initially, a surface muon beamline and a muSR application spectrometer will be constructed
b) Upgrade: add the second decay muon beamline to expand a total of 6 application terminals

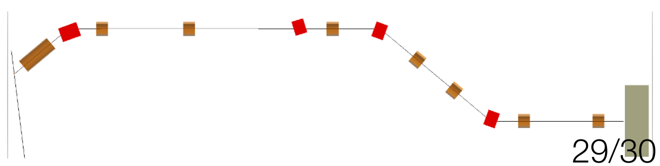


PARAMETERS	@CSNS-II	UPGRADE
Power (kW)	20	Up to 100
Proton Ek (GeV)	1.6	1.6
Repetition(Hz)	1	5
Surface muons P (MeV/c)	29.8	10-200
Requirement μ+/s	10^5	10^4-10^7
Polarization (%)	>90	50-95
Beam spot (mm*mm)	30*30	30*30
Number of detectors	1	6
Muons	surface	surface & decay

- MELODY has been approved (including its budget)
- All design parameters are under study



- μSR beamline with solenoidal and dipoles under optimization



Thank you very much
to all WG3 participants!